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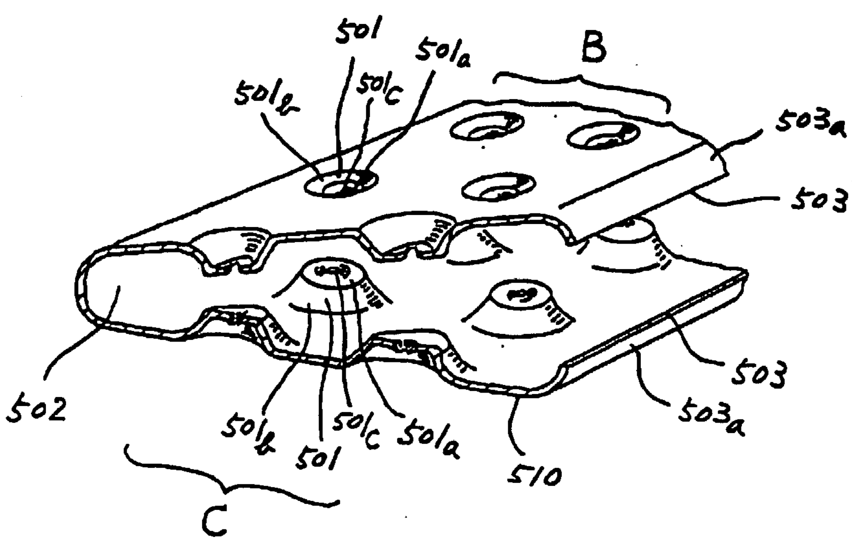
(54) Heat exchanger

(57) A heat exchanger, such as a condenser or an evaporator for an automotive air conditioning refrigerant circuit includes a plurality of tube elements each having a first planar portion and a second planar portion opposing the first planar portion. A plurality of projections are formed at an interior surface of the first and second planar portions. At least one hole is formed on a flat projecting end surface of the projection by piercing. The projections of the first and second planar portions are aligned with and face each other, and are fixedly connected to each other at their flat projecting end surfaces so that the at least one hole of the first and second projections face each other. This construction effectively increases the internal pressure resistance characteristics of the heat exchanger without causing an increase in a manufacturing cost thereof.

Fig. 9



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Description

The present invention generally relates to a heat exchangers for refrigerant circuits and, more particularly, to the heat medium conducting elements which constitute a heat exchanging area of the heat exchangers.

Various types of heat exchangers are known in the prior art. For example, Japanese Patent Application Publication No. 4-20794 discloses a heat exchanger, such as a condenser for use in an automotive air conditioning system as substantially illustrated in Figs. 1-3.

With reference to Figs. 1-3, the condenser 10' includes a plurality of adjacent, essentially flat tubes 11' each having a flat oval cross-section and a pair of open ends which allow refrigerant fluid to flow therethrough. Each flat tube 11' includes upper and lower flat surfaces 111 and 112 which are disposed in planes parallel to the direction of air flow as indicated by arrow "A" in Figs. 1 and 2, and opposite curved surfaces 113. One of the opposite curved surfaces 113 connects one end of upper flat surface 111 with one end of the lower surface 112 and the other of opposite curved surface 113 connects the other end of upper flat surface 111 with the other end of lower flat surface 112. A process of forming flat tube 11' is described in detail later. A plurality of corrugated fin units 12 are disposed between adjacent flat tubes 11'. Corrugated fin units 12 and flat tubes 11' are fixedly connected to each other by, for example, brazing, and form heat exchanger region 100.

A pair of cylindrical header pipes 13 and 14 each having opposite open ends are disposed perpendicular to flat tubes 11' and may have, for example, a clad construction. The opposite open ends of header pipes 13 and 14 are fixedly and hermetically plugged by respective caps 131, 132, 141 and 142 by, for example, being. A pair of channel members 15 and 16 are disposed on an upper and lower ends of heat exchange region 100, respectively. The channel member 15 includes a pair of leg portions 15a and a roof portion (not shown) which connects a lower end of the leg portions 15a, and the roof portion of channel member 15 is fixedly connected to the upper end of heat exchange region 100 by, for example, brazing. The longitudinal ends of channel member 15 are fixedly connected to an inside region of outer peripheral surface of the upper-most portion of header pipes 13 and 14, respectively, by, for example, being. Similarly, the channel member 16 includes a pair of leg portions 16a and a roof section (not shown) which connects an upper end of the leg portions 16a, and the roof portion of channel member 16 is fixedly connected to the lower end of heat exchange region 100 by, for example, being. The longitudinal ends of channel member 16 are fixedly connected to the inside region of the outer peripheral surface of the lower-most portion of header pipes 13 and 14, respectively, in the same manner as channel member 15. Channel members 15 and 16 reinforce the structural strength of the condenser 10'.

Circular opening 133, having a diameter slightly greater than an outer diameter of cylindrical inlet pipe 17, is formed at an upper portion of header pipe 13. After the termination of the brazing process, one end of the inlet pipe 17 is inserted into the opening 133 and is then fixedly and hermetically connected thereto, for example, by a separate process of brazing. Inlet pipe 17 is provided with a conventional union joint (not shown) at the other end thereof. Circular opening 143, having a diameter slightly greater than an outer diameter of cylindrical outlet pipe 18, is formed at a lower portion of header pipe 14. One end of outlet pipe 18 is inserted into the opening 143 and is then fixedly and hermetically connected thereto in the same manner as inlet pipe 17. Outlet pipe 18 is similarly provided with a conventional union joint (not shown) at the other end thereof. Inlet pipe 17 and outlet pipe 18 protrude from header pipe 13 perpendicular to the flat tubes 11'.

A plurality of slots 134 having an oval cross-section are formed at an inner side of header pipes 13 at equal intervals. Similarly, a plurality of slots (not shown) identical to slots 134 are formed at an inner side of header pipes 14 at equal intervals. The sizes of slots 134 are about equal to the outer sizes of flat tubes 11'. Header pipes 13 and 14, and flat tubes 11 are temporarily assembled to each other by forcibly inserting the opposite longitudinal ends of each of flat tubes 11' into the interior of header pipes 13 and 14 through slots 134.

Slot 135 is formed at an outer side of header pipes 13 and is located at a position which is slightly higher than the longitudinal center of header pipe 13 but is lower than inlet pipe 17. Slot 135 is arranged to be parallel to a plane perpendicular to the longitudinal axis of header pipe 13, and is angularly opened about 180°. Circular partition plate 191 is inserted into an inner hollow space of header pipe 13 through slot 135, and then is sealingly and fixedly connected to header pipe 13 by, for example, brazing. Thus, the inner hollow space of header pipe 13 is divided by the circular partition plate 191 into an upper portion 13a and a lower portion 13b. Similarly, slot 145 is formed at an outer side of header pipes 14 and is located at a position which is lower than the longitudinal center of header pipe 14 but is higher than outlet pipe 18. Slot 145 is arranged to be parallel to a plane perpendicular to the longitudinal axis of header pipe 14, and is angularly opened about 180°. Circular partition plate 192 is inserted into an inner hollow space of header pipe 14 through slot 145, and then is sealingly and fixedly connected to header pipe 14, by example, brazing. Thus, the inner hollow space of header pipe 14 is divided by the circular partition plate 192 into an upper portion 14a and a lower portion 14b.

By means of providing circular partition plates 191 and 192, the refrigerant flows through the heat exchange region 100 successively through first, second and third sections 100a, 100b and 100c. The first and second sections 100a and 100b have more flat tubes 11' located therein than the third section 100c.

Furthermore, the flat tubes 11', the fin units 12, the header pipes 13 and 14, the caps 131, 132, 141 and 142, the channel members 15 and 16, and circular partition

plates 191 and 192 are made of, for example, aluminum or aluminum alloy.

In a manufacturing process of the condenser 10' of this prior art embodiment, temporarily joined flat tubes 11' are prepared by the following sequential steps:

(1') In a first step, a metal sheet, such as an aluminum or aluminum alloy sheet (hereinafter, aluminum alloy sheet) 500 having a clad construction is prepared. The aluminum alloy sheet 500 is designed to have a predetermined width.

(2') In a second step, as illustrated in **Fig. 4**, a plurality of truncated cone projections 501 each having a circular flat top end portion 501a and a slanted annular side portion 501b are formed at one side surface of the aluminum alloy sheet 500 by, for example, press work. Truncated cone projections 501 are arranged to be aligned with a plurality of, for example, four rows which extend along the longitudinal axis of aluminum alloy sheet 500. Projections 501 are further arranged, such that one pair of rows "B" is spaced from the other pair of rows "C" with a certain interval which is greater than an interval measured between the adjacent rows of projections 501 in one of the pairs of rows "B" and "C". Circular hole 501c is centrally formed at the circular flat top end portion 501a of each of truncated cone projections 501 of one pair of rows "B" by, for example, punching at a time when the above press work is carried out.

(3') In a third step, the aluminum alloy sheet 500-processed in the above second step is separated into a plurality of rectangular sheets 510 having a certain length by, for example, press work, so that each of the rectangular sheets 510 has the certain width and length.

(4') In a fourth step, as illustrated in **Fig. 5**, rectangular sheet 510 is folded at a center of the planar portion 502, which is defined between the rows "B" and "C" along the longitudinal axis thereof by means of a well known folding manner so that both lateral ends 503 of rectangular sheet 510 face one another and the circular flat top end portion 501a of the corresponding projections 501 face one another. Furthermore, when the rectangular sheet 510 is folded, the planar portion 502 and both lateral end portions 503a of rectangular sheet 510 have the same radius of curvature. After rectangular sheet 510 is folded, both lateral ends 503 of rectangular sheet 510 and the circular flat top end portion 501a of the corresponding projections 501 are in fitting contact with each other at their mating surfaces. Thus, a temporarily joined flat tube 11' is prepared.

Furthermore, as substantially illustrated in Figs. 2 and 3, when the temporarily joined flat tube 11' is prepared, truncated cone projections 114 project from an inner surface of the temporarily joined flat tube 11', and lateral ends 503 of rectangular sheet 510 are connected at 115. Each of truncated cone projections 114 includes a circular flat top end portion 114a and a slanted annular side portion 114b. Each of the upper projections 114 further includes a centrally formed circular hole 114c.

After the temporarily joined flat tube 11' is prepared, the temporarily joined flat tubes 11', the corrugated fin units 12, the header pipes 13 and 14, the caps 131, 132, 141 and 142, the channel members 15 and 16, and circular partition plates 191 and 192 are all temporarily assembled with one another. Having temporarily assembled the condenser 10', the entire exterior surface of the condenser 10' is spray coated with flux dissolved in water. After this, the temporarily assembled condenser 10' is transported from an assembly line to a furnace in which a brazing process is carried out.

In this brazing process of the temporarily assembled condenser 10', some of the flux solution on the exterior surface of the temporarily assembled condenser 10' seeps into the small gaps created between the mating surfaces of circular flat top end portion 114a of the corresponding projections 114 through the circular hole 114c. In addition, some of the flux solution on the exterior surface of the temporarily assembled condenser 10' also seeps into the small gaps created between the mating surfaces of the lateral connecting ends 115.

Thus, the flux solution seeps into substantially all of the entire mating surfaces of the temporarily joined flat tubes 11'. Therefore, substantially all of the mating surfaces of the temporarily joined flat tubes 11' are sufficiently and effectively treated by the flux so that the aluminum oxide formed thereon is sufficiently removed when the mating surfaces of the temporarily joined flat tubes 11' are brazed to one another. Accordingly, the mating surfaces of the circular flat top end portion 114a of the corresponding projections 114, which are uniformly located around the inner surface of the flat tube 11', are effectively and sufficiently brazed to each other, so that the inner pressure resistance of flat tube 11' can be effectively increased.

In the flux treatment method described above, the water sprayed on the exterior surface of the temporarily assembled condenser 10' together with the flux is removed by for example, natural vaporization, before the temporarily assembled condenser 10' is transported from the assembly line to the furnace in which the being process is carried out.

Circular hole 501c is centrally formed at the circular flat top end portion 501a of each of truncated cone projections 501 by punching. Small circular scraps (not shown) are by-products of the punching process. These scraps may cause a defective operation of the press.

Specifically, when scraps stay on a mold (not shown) of a press machine (not shown), small projections may form on the aluminum alloy sheet 500 due to the existence of the scraps on the mold. If the small projections are formed at the circular flat top end portion 501a of the projections 501, the circular flat top end portion 501a of the corresponding projections 501 may not be in fitting contact with each other. As a result, the mating surfaces

of the circular flat top end portion 114a of the corresponding projections 114 may not be effectively and sufficiently brazed, so that the inner pressure resistance of flat tube 11' may not be effectively increased. In addition, the existence of the scraps on the mold may cause damage to the mold.

In order to avoid the above defects, a blower is sometimes used to blow off scraps punched from the projections 501 every operation of the press machine. However, a press machine equipped with such a blower is mechanically complicated and expensive, thereby causing an increase in the manufacturing cost of the condenser 10'.

Accordingly, it is an object of the present invention to provide a heat exchanger having a high inner pressure resistance without causing an increase in the manufacturing cost thereof.

In order to achieve this and other objects of the present invention, a heat exchanger in accordance with the present invention comprises at lease one tube element through which a beat medium flows. The tube element includes a first planar portion, a second planar portion opposing the first planar portion, and a plurality of projections formed at an interior surface of the first and second planar portions. Each of the projections includes a flat projecting end surface, at which at least one first hole is formed by piercing.

The projections formed at the interior surface of the first planar portion are aligned with and face the projections formed at the interior surface of the second planar portion. The projections formed at the interior surface of the first planar portion are fixedly connected to the corresponding projections formed at the interior surface of the second planar portion by aligning the respective holes with each other.

In the accompanying drawings:-

Fig. 1 is a perspective view of a heat exchanger, such as a condenser, in accordance with one prior art embodiment.

Fig. 2 is an enlarged partial perspective view of a flat tube shown in Fig. 1.

Fig. 3 is an enlarged lateral cross sectional view of the flat tube shown in Fig. 2.

Figs. 4 and 5 illustrate a part of the manufacturing process of the condenser shown in Fig. 1.

Fig. 6 is an enlarged partial perspective view of a flat tube which forms a part of a heat exchanger, such as a condenser, in accordance with a first embodiment of the present invention.

Figs. 7-10 illustrate a part of the manufacturing process of the condenser in accordance with the first embodiment of the present invention.

Fig. 11 is a perspective view of the temporarily assembled condenser in accordance with the first embodiment of the present invention, wherein a fixing jig is applied to the temporarily assembled condenser.

Fig. 12 is an enlarged literal cross sectional view of the flat tube shown in Fig. 6.

Fig. 13 is a schematic view illustrating a refrigerant flow in the condenser of the first embodiment.

Fig. 14 is a part of a manufacturing process of a condenser in accordance with a second embodiment of the present invention.

Fig. 15 is a perspective view of a heat exchanger, such as an evaporator, in accordance with a third embodiment of the present invention.

Fig. 16 is a plan view of a tube unit shown in Fig. 15.

Fig. 17 is an enlarged partial lateral cross sectional view of a temporarily joined tube unit of the third embodiment.

Fig. 18 is an enlarged partial longitudinal cross sectional view of the temporarily joined tube unit of the third embodiment.

Figs. 19 and 20 illustrate a part of a manufacturing process of the evaporator shown in Fig. 15.

Fig. 21 is a schematic view illustrating a refrigerant flow in the evaporator of the third embodiment.

Fig. 22 is a plan view of a tube unit of an evaporator in accordance with a fourth embodiment of the present invention.

Fig. 23 is a partial plan view of a tube unit of an evaporator in accordance with a fifth embodiment of the present invention.

Fig. 24 is a partial plan view of a tube unit of an evaporator in accordance with a sixth embodiment of the present invention.

Figs. 6-13 illustrate a heat exchanger, such as a condenser for use in an automotive air conditioning system in accordance with first embodiment of the present invention. In the drawings, like reference numerals are used to denote elements corresponding to those shown in Figs. 1-5, so a detailed explanation of the overall construction of the condenser in accordance with the first embodiment, with the exception of the flat tubes, may be obtained above.

In the manufacturing process of the condenser 10 of the first embodiment, temporarily joined flat tubes 11 are prepared by the following sequential steps:

(1) In a first step, a metal sheet, such as an aluminum or aluminum alloy sheet (hereinafter, aluminum alloy sheet) 500 having a clad construction is prepared. The aluminum alloy sheet 500 is designed to have a predetermined width.

(2) In a second step, as illustrated in Fig. 7, a plurality of truncated cone projections 501 each having a circular flat top end portion 501a and a slanted annular side portion 501b are formed at one side surface of the aluminum alloy sheet 500 by, for example, press work. Truncated cone projections 501 are arranged to be aligned with a plurality of, for example, four rows which extend along the longitudinal axis of aluminum alloy sheet 500. Projections 501 are further arranged such that rows "B" are spaced from rows

"C" with an interval which is greater than an interval measured between the adjacent rows of projections 501 in one of the pairs of rows "B" and "C". Circular hole 501c is centrally formed at the circular flat top end portion 501a of each of truncated cone projections 501.

A process of forming truncated cone projections 501 and a process of forming circular holes 501c are described in detail below with reference to Figs. 8(a)-8(f). Though only one truncated cone projection 501 is illustrated in Figs. 8(a)-8(f), a plurality of circular holes 501c are formed at one side surface of the aluminum sheet 500 simultaneously.

(2-1) First, as illustrated in Fig. 8(a), the aluminum alloy sheet 500 placed on a lower stationary mold 611 of a first pass machine 610 and then pressed by means of downwardly moving upper mold 612, so that, as illustrated in Fig. 8(b), a plurality of truncated cone projections 501 are formed at one side surface of the aluminum alloy sheet 500.

(2-2) Then, the aluminum alloy sheet 500 processed in the above step (2-1) is moved to a piercing machine 620 having a lower stationary mold 621, an upper movable mold 622 and a plurality of cylindrical piercing rods 623.

(2-3) Next, as illustrated in Fig. 8(c), the aluminum alloy sheet 500 processed in the above step (2-1) is fitly sandwiched between the lower stationary mold 621 and the upper movable mold 622.

(2-4) Then, the circular flat top end portion 501a of truncated cone projections 501 are centrally pierced by a cone-shaped pointed portion 623a of the corresponding piercing rods 623 by downwardly moving the piercing rods 623 through the corresponding cylindrical holes 622a which are formed through the upper movable mold 622. Thus, circular holes 501c are centrally formed at the circular flat top end portion 501a of the corresponding truncated cone projections 501 without producing small scraps. As illustrated in Fig. 8(d), the circular flat top end portion 501a of the truncated cone projections 501 is bent downwardly along a periphery of the corresponding cylindrical holes 621a so that a conical-shaped bent region 501d is formed at the periphery of the corresponding circular hole 501c. The pointed portion 623a of the piercing rods 623 penetrates the corrresponding cylindrical holes 621a which are formed through the lower stationary mold 621. An inner diameter of cylindrical boles 622a of the upper movable mold 622 is preferably smaller than that of cylindrical holes 621a of the lower stationary mold 621.

(2-5) Next, the aluminum alloy sheet 500 processed in step (2-4) is moved to the second press machine 630 having a lower stationary mold 631 and an upper movable mold 632.

(2-6) Finally, as illustrated in Fig. 8(e), the aluminum alloy sheet 500 processed in the above step (2-4) is fitly sandwiched between the lower stationary mold 631 and the upper movable mold 632 by downwardly moving the upper movable mold 632. Circular holes 501c are aligned and face the corresponding cylindrical holes 631a which are formed through the lower stationary mold 631. Since the inner diameter of cylindrical holes 631a is smaller than that of cylindrical hole 621a of the lower stationary mold 621 of the piercing machine 620, a part of the conical-shaped bent region 501d is bent flat by the molds 631 and 632. As a result, an area of the plane region of the circular flat top end portion 501a of truncated cone projections 501 increases while circular hole 501c narrows. The area of the plane region of the circular flat top end portion 501a of truncated cone projections 501 can be varied by changing the inner diameter of cylindrical hole 631a of the lower stationary mold 631.

(3) In the third step, the aluminum alloy sheet 500 is separated into a plurality of rectangular sheets 510 having a predetermined length and width by, for example, press work.

(4) In a fourth step, as illustrated in Fig. 9, rectangular sheet 510 is folded at a center of the planar portion 502 defined between the rows "B" and "C" along the longitudinal axis thereof by means of a well known folding manner. The lateral ends 503 of rectangular sheet 510 and the flat top end portion 501a of the corresponding projections 501 are aligned after folding. Furthermore, when the rectangular sheet 510 is folded, the planar portion 502 and the lateral end portions 503a of rectangular sheet 510 have substantially the same radius of curvature. After folding rectangular sheet 510, both lateral ends 503 of rectangular sheet 510 and the circular flat top end portion 501a of the corresponding projections 501 are in fitting contact with each other at their mating surfaces. Thus, a temporarily joined flat tube 11 is prepared.

Furthermore, as illustrated in Fig. 10, when the temporarily joined flat tube 11 is prepared, truncated cone projections 114 project from an inner surface of the temporarily joined flat tube 11. Each truncated cone projection 114 includes a circular flat top end portion 114a, a slanted annular side portion 114b, circular hole 114c centrally formed at the circular flat top end portion 114a, and the conical-shaped bent region 114d formed at the periphery of the circular hole 114c. Accordingly, the lateral connecting ends 115 and the circular flat top end portion 114a of the corresponding projections 114 are in fittingly contact with each other at their mating surfaces.

After the temporarily joined flat tube 11 is prepared, the temporarily joined flat tubes 11, the corrugated fin units 12, the header pipes 13 and 14, the caps 131, 132, 141 and 142, the channel members 15 and 16, and circular partition plates 191 and 192 are all temporarily assembled with one another at the same time. In order to effectively and sufficiently maintain the mating surfaces of the lateral connecting ends 115 and the circular flat top end portion 114a of the projections 114 of the temporarily joined flat tubes 11, a fixing jig 700 is applied to the temporarily assembled condenser 10 by a manner described below. The fixing jig 700 prevents relative sliding movement between the temporarily joined flat tubes 11 and the corrugated fin units 12 along the depth of the temporarily assembled condenser 10, as indicated by arrow "D" in Fig. 11.

With reference to Fig. 11, the fixing jig 700 includes a pair of cylindrical rods 701, two pairs of rectangular plates 702, and a pair of square pipes 703. Those elements constituting fixing jig 700 are made of, for example, stainless steel having a melting point sufficiently higher than that of aluminum and aluminum alloy. The square pipes 703 are snuggly received within the channel members 15 and 16 of the condenser 10, respectively. The pair of cylindrical rods 701 are arranged to extend in parallel to each other as indicated by arrow "H" in Fig. 11.

Both end portions of cylindrical rods 701 slidably penetrate through circular holes 702a formed in the pair of rectangular plates 702. One of the rectangular plates 702 contacts an upper side of square pipe 703, which is snuggly received within the channel member 15 of the condenser 10, and is fixedly secured to an upper portion of cylindrical rod 701 by any known securing manner. The other rectangular plate 702 contacts a lower side of square pipe 703, which is snuggly received within the channel member 16 of the condenser 10, and is fixedly secured to a lower portion of cylindrical rod 701 by any known securing manner. As a result, the upper and lower ends of heat exchange region 100 are held by the pair of the rectangular plates 702 through the square pipes 703.

Thus, the mating surfaces between the lateral connecting ends 115 of the temporarily joined flat tubes 11 and the mating surfaces of the circular flat top end portion 114a of the corresponding projections 114 are held in contact with each other. The relative sliding movement between the temporarily joined flat tubes 11 and the corrugated fin units 12 along the depth of the temporarily assembled condenser 10, as indicated by arrow "D" in Fig. 11, is effectively prevented.

The surfaces to be mated are then treated with flux so as to remove aluminum oxide thereon. When the process of applying the fixing jig 700 to the temporarily assembled condenser 10 as shown in Fig. 11 is completed, the condenser 10 is brazed, in general, in an inert gas, such as a helium gas atmosphere. In this process, the mating surfaces of the lateral connecting ends 115 and the mating surfaces of circular flat top end portion 114a of the corresponding projections 114 are brazed to each other.

According to the first embodiment, the non-corrosive flux is dissolved in water or alcohol diluted water, and sprayed on the entire exterior surface of the temporarily assembled condenser 10. Some of the flux solution on the exterior surface of the temporarily joined flat tubes 11 seeps into the small gaps created between the mating surfaces of circular flat top end portion 114a of the corresponding projections 114 through the circular hole 114c. In addition, some of the flux solution on the exterior surface of the temporarily joined flat tubes 11 also seeps into the small gaps between the mating surfaces of the lateral connecting ends 115.

Thus, the flux solution seeps into substantially all of the entire mating surfaces of the temporarily joined flat tubes 11. Therefore, substantially all of the entire mating surfaces of the temporarily joined flat tubes 11 are sufficiently and effectively treated by the flux so that the aluminum oxide formed thereon is sufficiently removed when the mating surfaces of the temporarily joined flat tubes 11 are brazed to one another. Accordingly, the mating surfaces of the circular flat top end portion 114a of the corresponding projections 114, which are uniformly located around the inner surface of the flat tube 11, are effectively and sufficiently brazed to each other, so that the inner pressure resistance of flat tube 11 can be effectively increased.

Furthermore, as illustrated in Fig. 12, after the brazing step, the periphery of the mating surfaces of the lateral connecting ends 115 and a periphery of the entire mating surfaces of the circular flat top end portion 114a of the corresponding projections 114 are covered with the thick brazing metal 116. Thus, substantially all of the mating surfaces of the temporarily joined flat tubes 11 are effectively and sufficiently brazed to each other.

The water or the alcohol solution sprayed on the exterior surface of the temporarily assembled condenser 10 is removed by, for example, natural vaporization, before the temporarily assembled condenser 10 is transported from an assembly line to a furnace in which a brazing process is carried out.

Furthermore, instead of spraying a flux solution, flux powder maybe absorbed on the entire exterior surface of the temporarily assembled condenser 10 by electrostatic absorption. According to this treatment method, the flux powder absorbed on the exterior surface of the temporarily joined flat tubes 11 is melted before the brazing metal sheet is melted, causing the melted flux to seep into substantially all of the mating surfaces of the temporarily joined flat tubes 11. Therefore, substantially all of the mating surfaces of the temporarily joined flat tubes 11 are sufficiently and effectively treated by the flux so that the aluminum oxide formed thereon is sufficiently removed when the mating surfaces of the temporarily joined flat tubes 11 are brazed to one another.

With reference to Fig. 13, operation of the above-constructed condenser 10 is described below. When the automotive air conditioning refrigerant circuit operates,

the gaseous phase refrigerant flows from a refrigerant compressor (not shown) of the refrigerant circuit through inlet pipe 17 into the upper portion 13a of the inner hollow space of header pipe 13. The refrigerant flowing into the upper portion 13a of the inner hollow space of header pipe 13 concurrently flows through the flat tubes 11 located in the first section 100a of the heat exchange region 100 while exchanging heat with the air passing along corrugated fin units 12, and into an upper region of the upper portion 14a of the inner hollow space of header pipe 14. The refrigerant in the upper region of the upper portion 14a then flows downwardly to a lower region of the upper portion 14a. The refrigerant in the lower region of the upper portion 14a of the inner hollow space of header pipe 14 then concurrently flows through the flat tubes 11 located in the second section 100b of the heat exchange region 100 while also exchanging heat with the air passing along corrugated fins 12. Then, the refrigerant flows into an upper region of the lower portion 13b of the inner hollow space of header pipe 13. The refrigerant in the upper region of the lower portion 13b then flows downwardly to a lower region of the lower portion 13b. The refrigerant in the lower region of the lower portion 13b of the inner hollow space of header pipe 13 then concurrently flows through the flat tubes 11 located in the third section 100c of the heat exchange region 100 while further exchanging heat with the air passing along corrugated fins 12. Then, the refrigerant flows into the lower portion 14b of the inner hollow space of header pipe 14. The condensed, i.e., liquid phase, refrigerant located in the lower portion 14b of the inner hollow space of header pipe 14 flows to an inlet port of an evaporator (not shown) of the refrigerant circuit (not shown) via a throttling device, such as an expansion valve through outlet port 18.

According to the first embodiment of the present invention, as described in the step (2-4) of the manufacturing process of the condenser 10, no small scraps are produced when the circular holes 501c are formed at the circular flat top end portion 501a of the truncated cone projections 501. Therefore, condensers having a high inner pressure resistance are manufactured without using expensive punches.

Furthermore, since the intervening spaces between the adjacent flat tubes 11 in which corrugated fin units 12 are disposed communicate with one another through the circular holes 114c, the distribution of the air passing through each of the intervening spaces is generally uniform even if the flow distribution of the air immediately before the heat exchange region 100 is uneven. Accordingly, the heat exchange between the refrigerant in the flat tubes 11 and the air passing cough the heat exchange region 100 of condenser 10 is effectively carried out. In addition, circular holes 114c increase the surface area of the flat tubes 11 exposed to the air. As a result, the heat exchange efficiency of condenser 10 is enhanced.

Fig. 14 illustrates a part of a manufacturing process of a condenser in accordance with a second embodiment of the present invention. In the second embodiment, flat tube 11 is prepared by joining a pair of rectangular plates 511, which includes a plurality of truncated cone projections 501 and curved lateral end portions 511a. The projections 501 and the curved lateral end portions 511a are formed at the same time in a step similar to the above-described step (2-1). The other steps of the manufacturing process of condenser 10 of the second embodiment are similar to those of the condenser 10 of the first embodiment so that an explanation thereof is omitted. Further, the effects of the second embodiment are similar to those of the first embodiment so that an explanation thereof is also omitted.

Fig. 15 illustrates an overall construction of a heat exchanger, such as a laminated type evaporator 20, in accordance with a third embodiment of the present invention. The laminated evaporator 20 is generally used in an automotive air conditioning system. With reference to **Fig. 15**, the laminated evaporator 20 includes a plurality of tube units 21 of aluminum or aluminum alloy functioning as the heat medium conducting elements, which form a heat exchanging area 200 of evaporator 20 together with corrugated fins 22. As illustrated in **Fig 16**, each of tube units 21 comprises a pair of tray-shaped plates 211 having a clad construction where a bag metal sheet is formed on a core metal.

With reference to **Fig. 16**, each of tray-shaped plates 211 includes a shallow depression 211a defined therein, a flange 212 forms around the periphery thereof, and a narrow wall 213 formed in the central region thereof. Narrow wall 213 extends downwardly from an upper end of plate 211 and terminates approximately one-fifth of the length of plate 211 away from the lower end thereof. Narrow wall 213 includes a flat top surface 213a. As illustrated in **Figs. 17 and 18**, a plurality of truncated cone projections 214 project from the inner bottom surface of shallow depression 211a. Each of projections 214 includes a circular flat top end portion 214a, a slanted annular side portion 214b, circular hole 214c centrally formed at the circular flat top end portion 214a, and the conical-shaped bent region 214d formed at the periphery of the circular hole 214c. The truncated cone projections 214 are uniformly located around the inner bottom surface of shallow depression 211a of plate 211, and are arranged to be diagonally aligned with one another. Thus, cylindrical projections 214 are utilized in order to reinforce the mechanical strength of plate 211.

Each of tray-shaped plates 211 further includes a pair of connecting tongues 215 projecting upwardly from the upper end thereof. One of the tongues 215 is disposed to the right of narrow wall 213, and the other tongue 215 is disposed to the left thereof. A depression 215a is formed in the center of tongue 215, and longitudinally extends from the upper end to the lower end thereof, and is linked to shallow depression 211a of plate 211. The bottom surface of depression 215a is formed even with the plane of thus inner bottom surface of shallow depression 211a. A plurality of diagonally arranged cylindrical projections 214 also project from the inner

bottom surface of depression 215a to reinforce the mechanical strength of tongues 215.

The flat top surface 213a of narrow wall 213, the flat top end surface of each of tongues 215, and the plane surface of circular flat top end portion 214a of truncated cone projections 214 are preferably substantially even with the plane surface of flange 212. Therefore, when the pair of tray-shaped plates 211 are joined, the pair of tongues 215 form a pair of cylindrical hollow connecting portions 215b as shown in Fig. 18, a U-shaped passage 216 is defied therebetween as shown in Fig. 16, narrow walls 213 of each plate 211 contact one another at the flat top surfaces 213a, and the plane surfaces of truncated cone projections 214 contact one another. Flanges 212, narrow walls 213 and truncated cone projections 214 are fixedly attached to each other at their mating surfaces by, for example, brazing.

The laminated type evaporator 20 further includes a pair of parallel closed generally semicylindrical header pipes 23 and 24 situated above the upper surface of laminated tube units 21. As illustrated in Fig. 15, semicylindrical pipe 23 is positioned in front of semicylindrical pipe 24. Semicylindrical pipe 23 includes a plurality of, for example, four narrowed portions 230 which are located along the longitudinal axis thereof. Similarly, semicylindrical pipe 24 also includes a plurality of, for example, four narrowed positions 240 which are located along the longitudinal axis thereof. By means of providing narrowed portions 230 and 240, semicylindrical pipes 23 and 24 can sufficiently resist high inner pressure.

A plurality of generally oval-shaped slots (not shown) are formed along the flat bottom surface of semicylindrical pipes 23, 24 at equal intervals. Generally, the oval-shaped slots of pipe 23 are aligned with the oval-shaped slots of pipe 24 so as to receive the pair of cylindrical hollow connecting portions 215b. The pair of cylindrical hollow connecting portions 215b are inserted into the slots of semicylindrical pipes 23 and 24 until the side surface of oval ridge 215c formed at an outer surface of an upper region of cylindrical hollow connecting portions 215b contacts a peripheral portion of the slots of semicylindrical pipes 23 and 24. The pair of cylindrical hollow connecting portions 215b are fixedly attached to slots of semicylindrical pipes 23 and 24, respectively, by, for example, brazing.

A pair of circular openings 231 and 232 are formed at the right and left ends of semicylindrical pipe 23, respectively, on the front curved surface thereof. After the brazing process is complete, one end of inlet pipe 25 is inserted into the opening 231 and is then fixedly and hermetically connected thereto, for example, by a separate brazing process. Inlet pipe 25 is provided with a conventional union joint (not shown) at the other end thereof. Similarly, one end of outlet pipe 26 is inserted into the opening 232 and is then fixedly and hermetically connected thereto in the same manner as inlet pipe 25. Outlet pipe 26 is similarly provided with a conventional union joint (not shown) at the other end thereof.

Semicircular plate 233 is fixedly disposed at an intermediate location within the interior region of cylindrical pipe 23 so as to divide the interior region of the semicylindrical pipe 23 into a right side section 23a and a left side section 23b.

A rectangular flange 217 projects from the lower end of plate 211, and is bent downwardly in a generally right angle at the terminal end thereof. The downwardly bent portion 217a of adjacent flanges 217 are attached to each other so that an intervening space 27 is formed between the adjacent tube units 21.

The heat exchanging area 200 of evaporator 20 is formed by laminating together a plurality of tube units 21 and inserting corrugated fins 22 within the intervening spaces 27 between the adjacent tube units 21. A pair of side plates 28 are attached to the right side of plate 211b which is located on the far right side of evaporator 20 and the left side of plate 211c which is located on the far left side of evaporator 20, respectively, and corrugated fins 22 are disposed between side plate 28 and plate 211b, and between side plate 28 and plate 211c, respectively. The lower end pertion of side plate 28 includes a rectangular flange 28a projecting inwardly and then bent downwardly in a generally right angle at the terminal end thereof. Respective tube units 21, corrugated fins 22, and side plates 28 are fixedly attached to one another by any conventional manner, such as brazing, for example. Although corrugated fins 22 are only illustrated in Fig. 15 at the upper and lower ends of intervening spaces 27, corrugated fins 22 continually extend along the entire length of intervening spaces 27.

The preferred manufacturing process of the evaporator 20 of the third embodiment is described in detail below with reference to Figs. 17-20:

First, the tray-shaped plate 211 is formed from a rectangular aluminum or aluminum alloy sheet (not shown) by, for example, press work by simultaneously forming the shallow depression 211a, flange 212, the narrow wall 213, the pair of connecting tongues 215, and the rectangular flange 217.

Then, a plurality of truncated cone projections 214 are formed at the bottom surface of shallow depression 211a of plate 211 in a manner substantially similar to the second step of the manufacturing process of condenser 10 of the first embodiment described in detail above.

Finally, the tray-shaped plates are joined to each other along the plane surface of the flanges 212, the flat top surface 213a of the corresponding narrow walls 213, the flat top surface of the corresponding tongues 215, and the plane surface of circular flat top end portion 214a of the corresponding truncated cone projections 214.

After the temporarily joined tube unit 21 is prepared, the temporarily joined tube units 21, the corrugated fins 22, the semicylindrical header pipes 23 and 24, the side plates 28, and semicircular plate 233 are all temporarily assembled with one another at the same time. In order to effectively and sufficiently maintain the mating surfaces of the flanges 212, narrow walls 213, the circular flat top end portion 214a of the truncated cone projec-

tions 214, and the tongues 215, a fixing jig 800 is applied to the temporarily assembled evaporator 20. Fixing jig 800 effectively prevents relative sliding movement of tube units 21 and the corrugated fins 22 in the depth direction of the temporarily assembled evaporator 20, as indicated by arrow "D" in **Fig. 19**.

With reference to **Figs. 19** and **20**, the fixing jig 800 includes a pair of frame assemblies 810 within which the temporarily assembled evaporator 20 is disposed, and a pair of rectangular holding plates 820 which are disposed at the far right side and the far left side of the evaporator 20, respectively. Holding plate 820 preferably has substantially the same length and width as tube unit 21. Each of frame assemblies 810 include a pair of cylindrical rods 811, a pair of rectangular plates 812, and a T-bar bolt 813. Each element in the fixing jig 800 are made of materials, for example, stainless steel, which have melting points sufficiently higher than that of aluminum and aluminum alloy.

With respect to each of the flame assemblies 810, the pair of cylindrical rods 811 are arranged to extend in parallel to each other along the length of the temporarily assembled evaporator 20 as indicated by arrow "L" in **Fig. 19**. The cylindrical rods 811 extend through the pair of rectangular plates 812, and are fixedly connected thereto by any known fitting method. T-bar bolt 813 is screwed into a female-screw threaded circular hole 812a centrally formed through the rectangular plate 812 located at the left hand side of the evaporator 20.

One end of bolt 813 thus pushes the holding plate 820, which is located at the left hand side of the evaporator 20, toward the right hand side a indicated by arrow "E" in **Fig. 20** until the pair of the holding plates 820 engage the side plates 28 of evaporator 20. When the temporarily assembled evaporator 20 is firmly sandwiched by the pair of rectangular holding plates 820, the pair of frame assemblies 810 are arranged such that they are located at upper and lower portions of the evaporator 20, respectively, as illustrated in **Fig. 19**. As a result, the right and left side ends of the temporarily assembled evaporator 20 are forced together by the pair of holding plates 820 so that the mating surfaces of the flanges 212, narrow walls 213, the circular flat top end portion 214a of the truncated cone projections 214, and the tongues 215 are effectively and sufficiently maintained in fitting contact with each other. Consequently, the temporarily joined tube units 21 and the corrugated fins 22 are prevented from sliding in the depth direction, as indicated by arrow "D" in **Fig. 19**.

After the jig is secured, flux solution applied on the exterior surface of the temporarily assembled tube unit 21 seeps into the small gaps created between the mating surfaces of the circular first top end portion 214a of the corresponding truncated cone projections 214 through the circular hole 214c. Aluminum oxide formed on the mating surfaces is sufficiently removed so that the mating surfaces can be effectively brazed to each other.

During operation of the automotive air conditioning refrigerant circuit, the refrigerant flows from a condenser (not shown) of the refrigerant circuit via a throttling device, such as an expansion valve, through inlet pipe 25 into right side section 23a of the interior region of semicylindrical pipe 23. The refrigerant flowing into right side section 23a of the interior region of semicylindrical pipe 23 concurrently flows through the interior region of cylindrical hollow connecting portions 215b and into the upper right region of U-shaped passage 216 in each of tube units 21. The refrigerant in the upper right region of U-shaped passage 216 then flows downwardly to the lower right region of U-shaped passage 216 in a complex flow path, which includes diagonal and straight flow paths as shown by the solid arrows in **Fig. 16**, while exchanging heat with the air passing along corrugated fins 22 in the direction as indicated by arrow "A" in **Fig. 15**. The refrigerant located in the lower right region of U-shaped passage 216 is turned at the terminal end of narrow wall 213 and directed from the right to the left side of U-shaped passage 216, as shown by the solid arrows in **Fig. 16**. That is, the refrigerant flows from We front to the rear of U-shaped passage 216, then flows upwardly to the upper left region of U-shaped passage 216 in a complex flow path while further exchanging heat with the air passing along corrugated fins 22, and then finally flows out of U-shaped passage 216 in each of the tube units 21 through cylindrical hollow connecting portion 215b. The refrigerant flowing out of U-shaped passage 216 from each of tube units 21 combines in the interior region of semicylindrical pipe 24 and flows therethrough in a direction from the right side to the left side thereof.

The refrigerant flowing through the interior region of the left side of semicylindrical pipe 24 concurrently flows into the upper left region of U-shaped passage 216 in each of tube units 21 through cylindrical hollow connecting portion 215b. The refrigerant then flows downwardly to We lower left region of U-shaped passage 216 in a complex flow path and exchanges heat with the air passing along corrugated fins 22. The refrigerant located in the lower left region of U-shaped passage 216 is turned at the terminal end of narrow wall 213 and directed from the left side to the right side of U-shaped passage 216. That is, the refrigerant flows from the rear to the front of U-shaped passage 216, then flows upwardly to the upper right region of U-shaped passage 216 in a complex flow path while further exchanging heat with the air passing along corrugated fins 22, and finally flows out of U-shaped passage 216 from each of tube units 21 through cylindrical hollow connecting portions 215b. The refrigerant flowing from U-shaped passage 216 in each of tube units 21 combines in the left side section 23b of the interior region of semicylindrical pipe 23. The gaseous phase refrigerant located in the left side section 23b of the interior region of semicylindrical pipe 23 flows through outlet pipe 26 to the suction chamber of a compressor (not shown) in the refrigerant circuit.

According to the third embodiment, the mating surfaces of the circular flat top end portion 214a of the corresponding projections 214, which are uniformly located around the inner surface of the tube unit 21, are effec-

tively and sufficiently brazed to each other, so that the inner pressure resistance of tube units 21 is effectively increased.

Furthermore, the adjacent intervening spaces 27 defined between the adjacent tube units 21 in which corrugated fins 22 are disposed communicate through circular holes 214c formed through the circular flat top end portion 214a of the corresponding projections 214. As a result, the amount of air flowing through the intervening spaces 27 is generally uniform even when the flow of the air immediately before the heat exchange region 200 has an uneven distribution. Accordingly, the heat exchange between the refrigerant in the tube units 21 and the air passing through the heat exchange region 200 of evaporator 20 is efficiently and effectively carried out. In addition, circular holes 114c increase the exterior fin surface area of the tube units 21 exposed to the air passing through the heat exchange area 200, thereby improving the heat exchange efficiency.

Fig. 22 illustrates a plan view of a tube unit 21 of an evaporator in accordance with a fourth embodiment of the present invention. In this embodiment, flanges 211 of tray-shaped plates 211 are integrally connected to each other. A planar region 212a is defined between the adjacent lateral end of plates 211. In the manufacturing process of the evaporator of this embodiment, a temporarily joined tube unit 21 is prepared by folding a center of the planar region 212a. The other features and effects of this embodiment are similar to those of the third embodiment, so that an explanation thereof is omitted.

Fig. 23 illustrates a partial plan view of a tube unit 21 of an evaporator in accordance with a fifth embodiment of the present invention. In this embodiment, some of the truncated cone projections 214 located at a central region of the bottom surface of shallow depression 211a are replaced with projections 414 each having an elliptic flat top end portion 414a, and the truncated cone projections 214 located at a lower right and lower left corner regions of the bottom surface of shallow depression 211a are replaced with a pair of projections 514 each having a triangular flat top end portion 514a.

A pair of circular holes 414c are formed at the longitudinal end regions of the elliptic flat top end portion 414a of projection 414, and three circular holes 514c are formed at the three corner regions of the triangular flat top end portion 514a of projections 515. The method of forming holes is substantially similar to the manner described in steps (2-2) - (2-6) of the manufacturing process of condenser 10 of the first embodiment, so an explanation thereof is omitted.

According to this embodiment, since the mating surface area of the temporarily joined tube units 21 is increased due to the larger projection, the inner pressure resistance of tube unit 21 is effectively increased. The other features and effects of this embodiment are similar to those of the third embodiment, so an explanation thereof is omitted.

Fig. 24 illustrates a partial plan view of a tube unit 21 of an evaporator in accordance with a sixth embodiment of the present invention. In this embodiment, in place of the circular holes 414c, a single elliptic hole 414c' is formed along the longitudinal axis of the elliptic flat top end portion 414a. In addition, a plurality of circular openings 214c' are formed at equal intervals on the plane surface 213a of narrow wall 213. The method of forming elliptic holes 414c' is substantially similar to the method described in steps (2-2) - (2-6) of the manufacturing process of condenser 10 of the first embodiment, with the exception that a cylindroidal piercing rod having an elongated edge at its lower end is employed in the piercing machine 620 in place of the cylindrical piercing rod 623 having the cone-shaped pointed portion 623a at its lower end. Thus, a detailed explanation of the manner of forming elliptic holes 414c' simply requires a review of the earlier explanation.

According to this embodiment, inasmuch as some of the flux solution on the exterior surface of the temporarily joined tube unit 21 seeps into the small gap created between the mating surfaces of the corresponding narrow walls 213 through circular openings 214c', narrow walls 213 are effectively and sufficiently brazed to each other. Accordingly, the inner pressure resistance of tube unit 21 is effectively increased. Other features and effects of this embodiment are similar to those of the third embodiment, so a detailed explanation simply requires a review of the earlier explanation.

Claims

1. A heat exchanger comprising:

   at least one tube element through which a first fluid flows, said tube element including a first planar portion, a second planar portion opposing said first planar portion, and a plurality of projections formed at an interior surface of said first and second planar portions, each of said projections including a flat projecting end surface in which at least one first hole is formed;

   said projections formed at the interior surface of said first planar portion aligned with and face said projections formed at the interior surface of said second planar portion;

   said flat projecting end surface formed on said projections on the interior surface of said first planar portion fixedly connected to corresponding said flat projecting end surface formed on said projections on the interior surface of said second planar portion so that the at least one first holes are aligned with one another.

2. The heat exchanger of claim 2 wherein said projections are truncated cone-shaped.

3. The heat exchanger of claim 2 wherein said flat projecting end surface is circular.

4. The heat exchanger of claim 3 wherein said at least one first hole includes a single circular hole.

5. The heat exchanger of claim 1, said heat exchanger further comprising at least one first member through which a second fluid passes, said at least one fin member being fixedly disposed on an exterior surface of said planar portions.

6. The heat exchanger of claim 1, said at least one tube element further including a pair of walls disposed at an intermediate location in an interior surface of said first and second planar portions and extending a portion of the length of said first and second planar portions, respectively, each of said walls including a flat top end surface in which at least one second hole is formed;

said walls arranged such that one wall disposed at the interior surface of the first planar portion is aligned with and faces other wall disposed at the interior surface of the second planar portion;

said one wall disposed at the interior surface of said first planar portion fixedly connected at their flat top end surfaces to the wall disposed at the interior surface of said second planar portion by aligning said at least one second hole of the pair of walls, said walls thereby defining a pair of interior regions in said at least one tube element.

7. The heat exchanger of claim 6 wherein said at least one second hole includes a single circular hole.

8. The heat exchanger of claim 6 wherein said projections are truncated cone-shaped.

9. The heat exchanger of claim 8 wherein said flat projecting end surface is circular.

10. The heat exchanger of claim 8 wherein said at least one first hole includes a single circular hole.

11. The heat exchanger of claim 6 further comprising generally triangular projections formed in said interior surface of said first and second planar portions.

12. The heat exchanger of claim 11 wherein said flat projecting end surface of said triangular projections are generally triangular.

13. The heat exchanger of claim 12 wherein said at least one first hole includes a plurality of circular holes.

14. The heat exchanger of claim 13 wherein said at least one first hole includes three circular holes.

15. The heat exchanger of claim 6 further comprising generally elliptical projections formed in said interior surface of said first and second planar portions.

16. The heat exchanger of claim 15 wherein said flat projecting end surface of said elliptical projections are elliptic.

17. The heat exchanger of claim 16 wherein said at least one first hole includes a single circular hole.

18. The heat exchanger of claim 16 wherein said at least one first hole includes a plurality of circular holes.

19. The heat exchanger of claim 18 wherein said at least one first hole includes a pair of circular holes which are located at longitudinal end portions of said elliptic flat projecting end surface of said projection.

20. A method for forming a heat exchanger, said heat exchanger including at least one tube element through which a first fluid flows, said tube element including a first planar portion, a second planar portion opposing said first planar portion, and a plurality of projections formed at an interior surface of said first and second planar portions, each of said projections including a flat projecting end surface in which at least one hole is formed and at least one fin member through which a second fluid passes, said at least one fin member fixedly disposed on an exterior surface of said planar portions; the method comprising the steps of:

forming said projections by press work; and
forming said at least one hole by piercing.

21. The method for forming the heat exchanger of claim 20, further comprising the steps of:

mating the flat projecting end surface of the projections formed on the interior surface of the first planar portion with the flat projecting end surface of the projections formed on the interior surface of the second planar portion;

temporarily assembling said at least one tube element and said at least one fin member;

coating an exterior surface of said at least one tube element with a flux; and

brazing the mating surfaces of the projections at the interior surface of said first and second planar portions in an inert gas.

22. The method for forming the heat exchanger of claim 21 wherein the entire exterior surface of said at least one tube element is coated with the flux.

23. The method for forming the heat exchanger of claim 21 wherein said flux is non-corrosive flux.

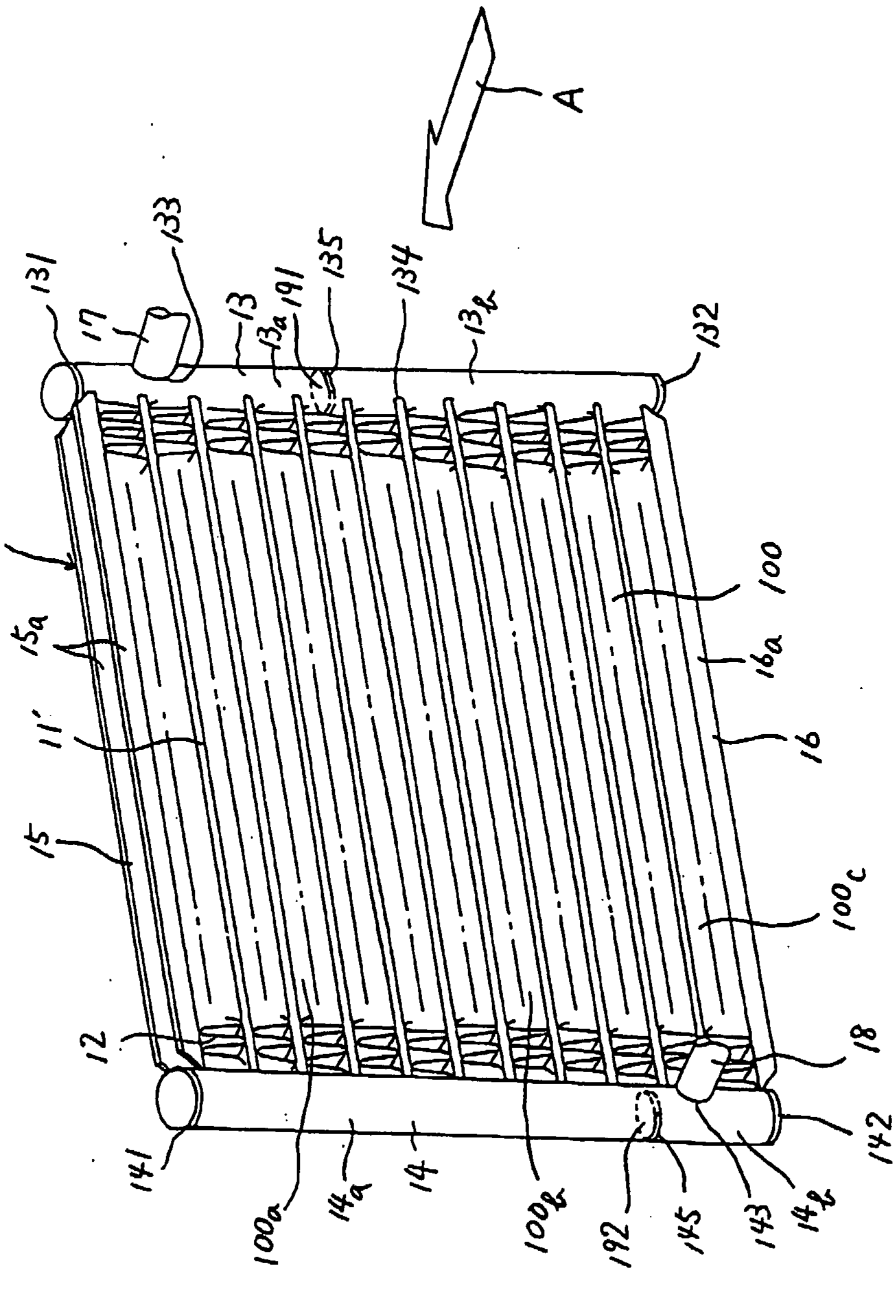

Fig. 1
(Prior Art)

Fig. 2
(Prior Art)

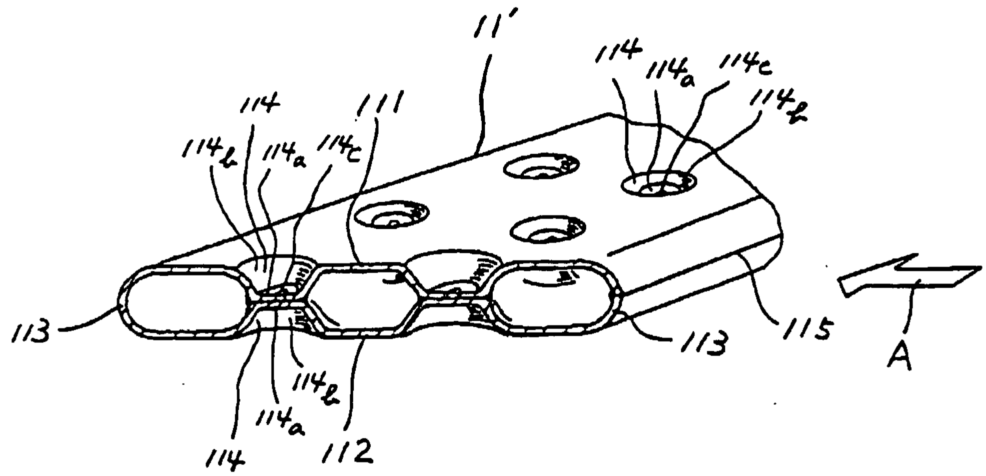

Fig. 3
(Prior Art)

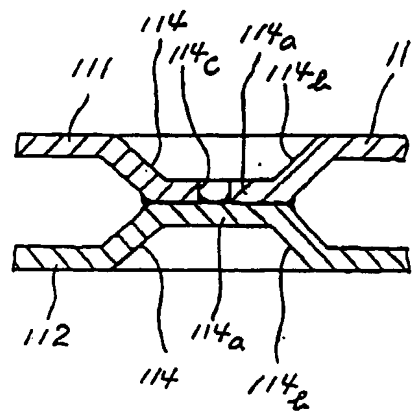

Fig. 4
(Prior Art)

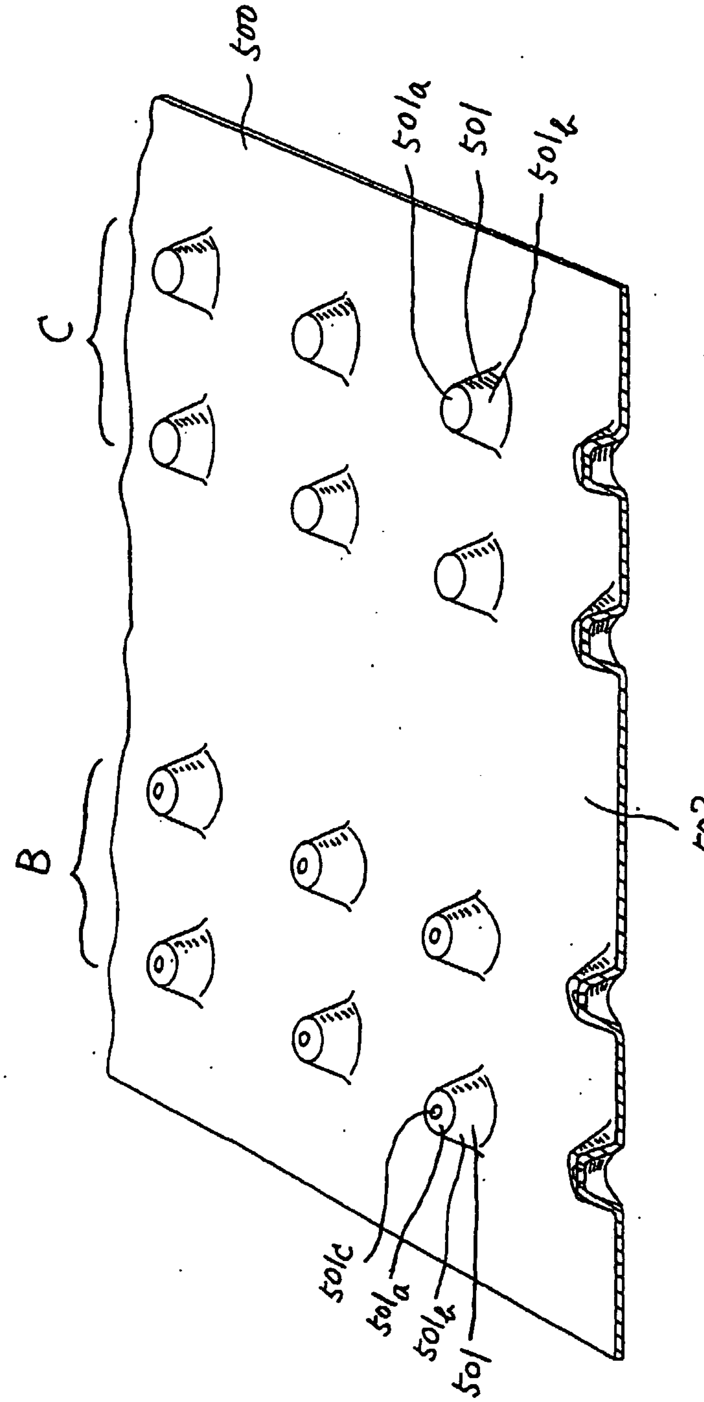

Fig. 5
(Prior Art)

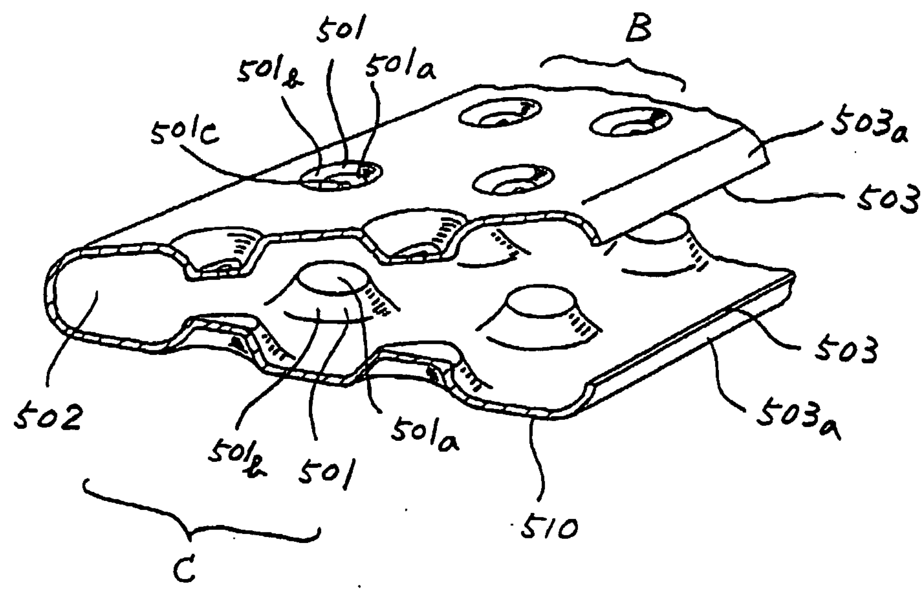

Fig. 7

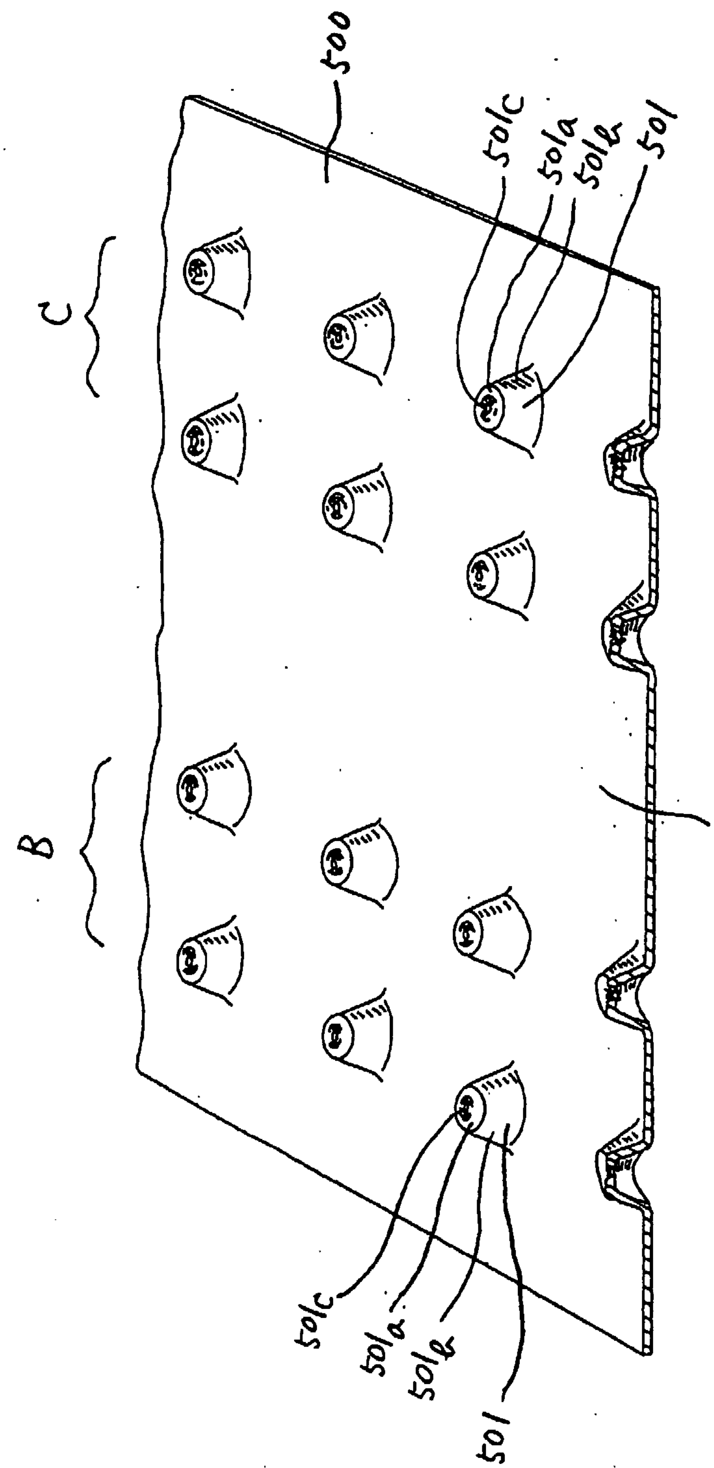

Fig. 6

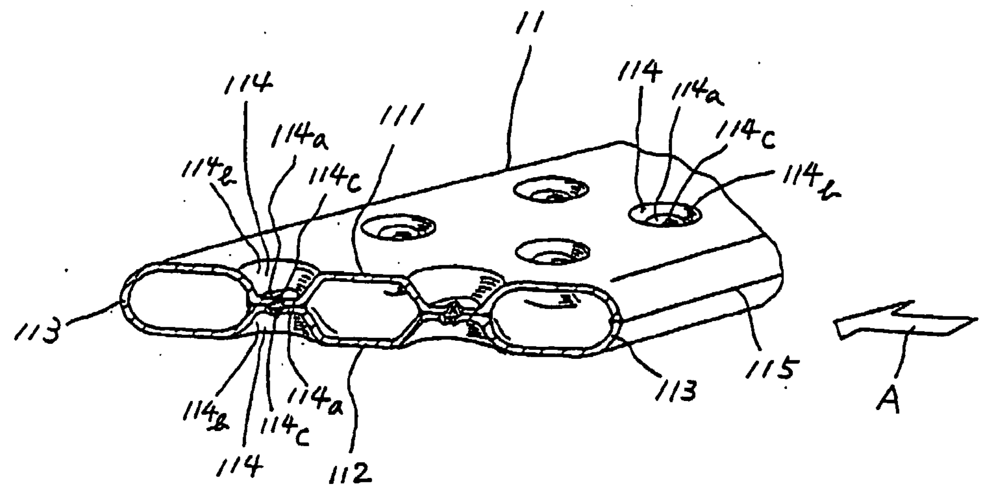
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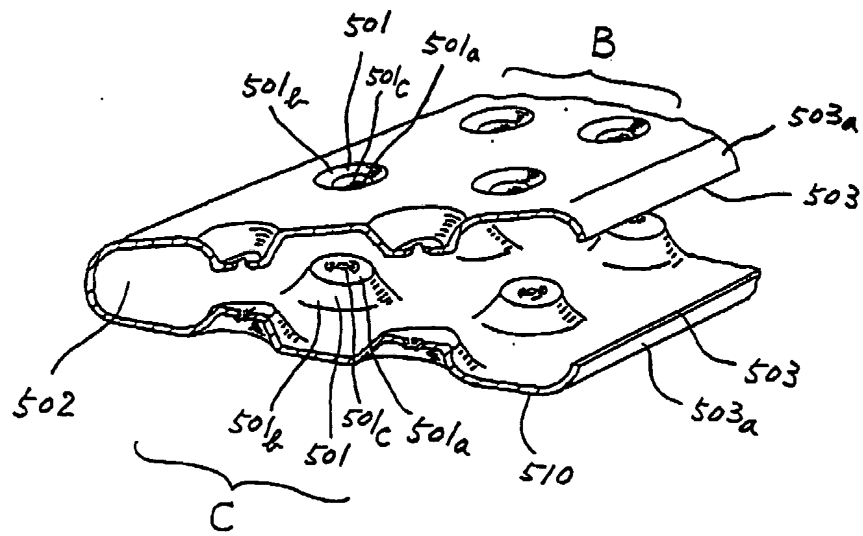
Fig. 9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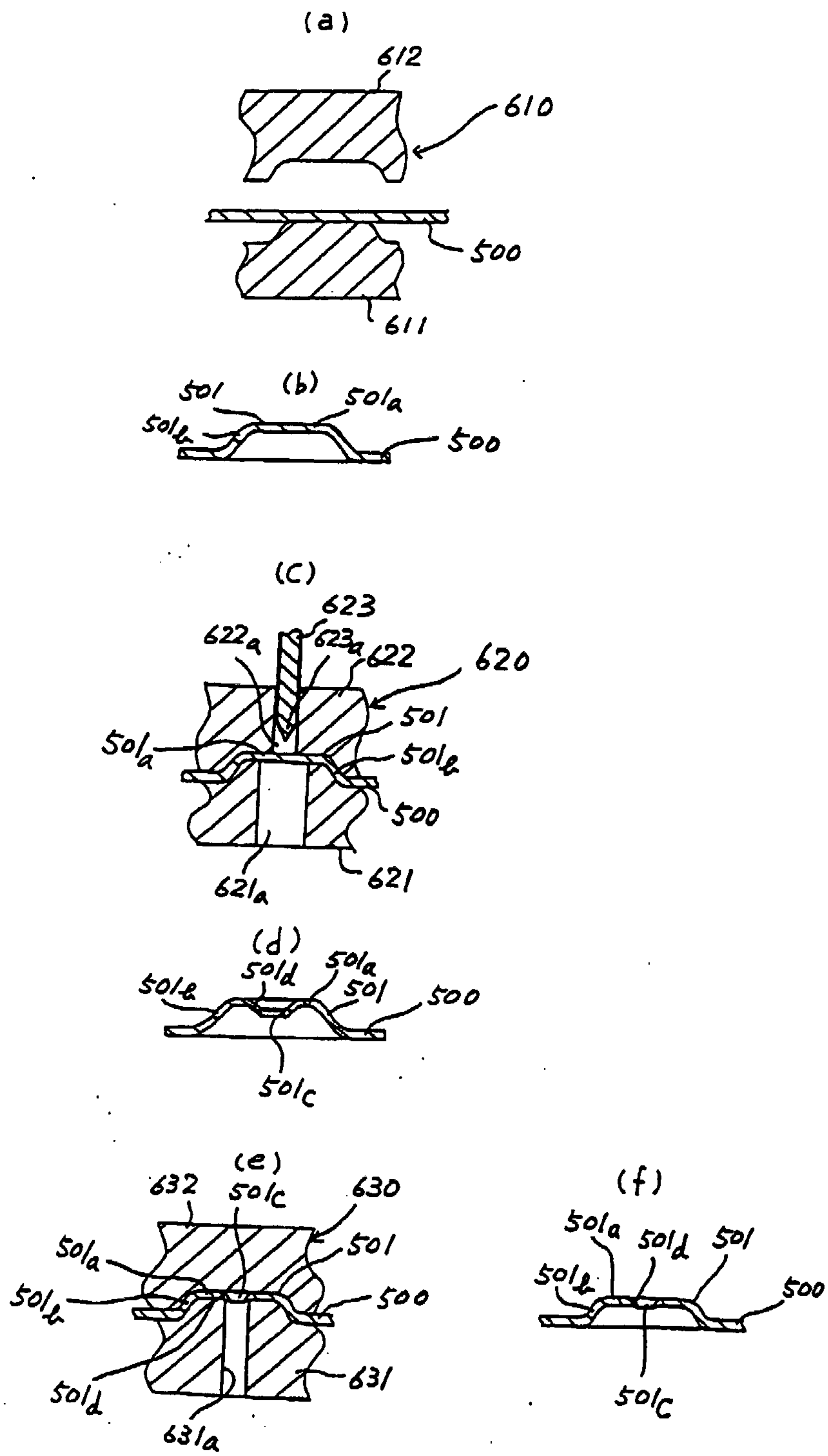
C

Fig. 8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(b)
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(C)
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501a
501b
500
621a
621
(d)
501b
501d
501a
501
500
501c
(e)
632
501c
630
501a
501
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500
501d
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501
501b
500
501c

Fig. 10

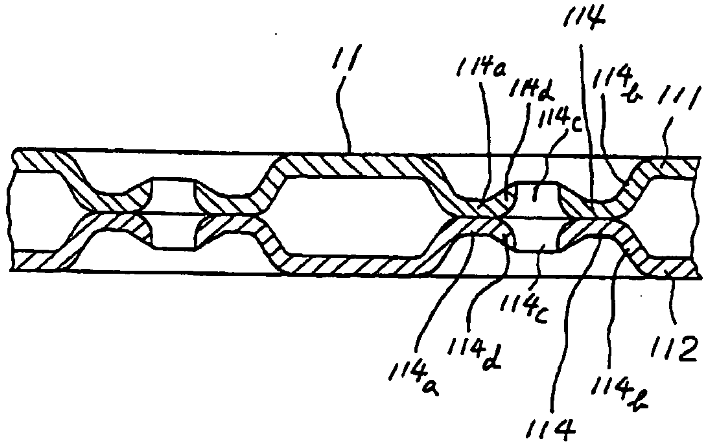
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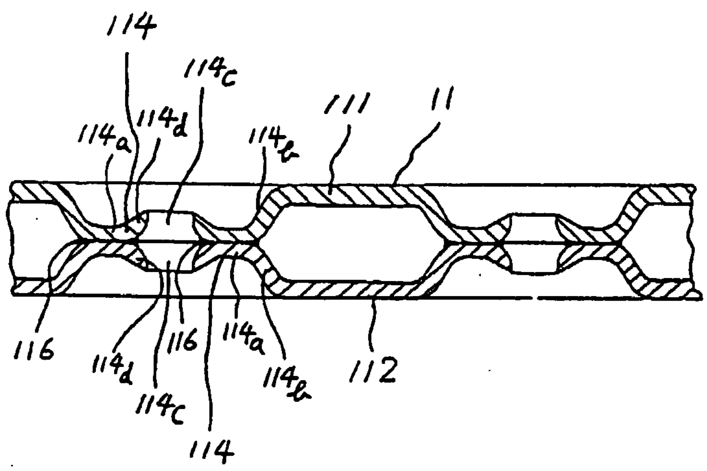
Fig. 12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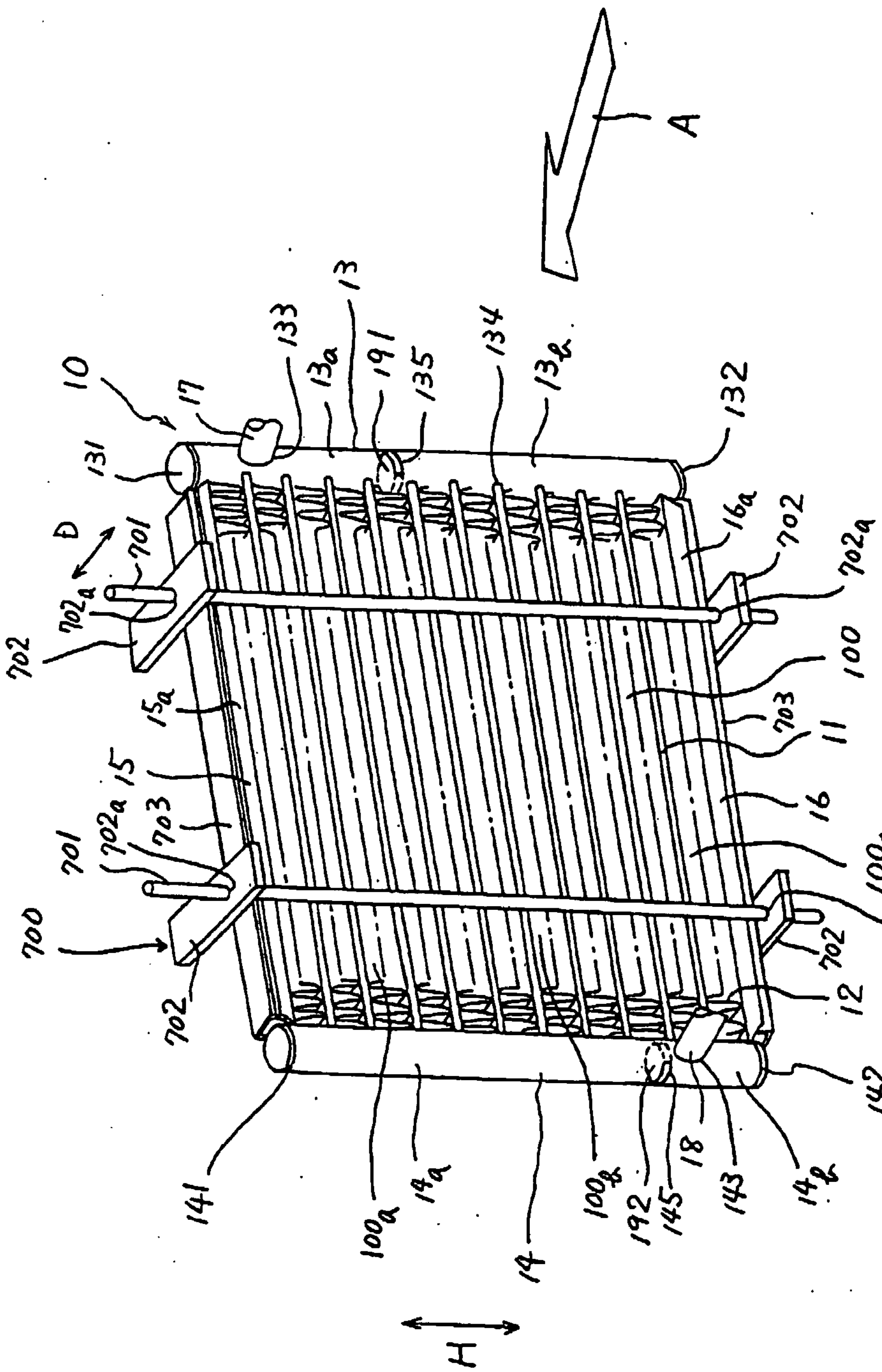
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16
100c
15a
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700
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14a
14
100b
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145
18
143
14b
H

Fig. 11

Fig. 13

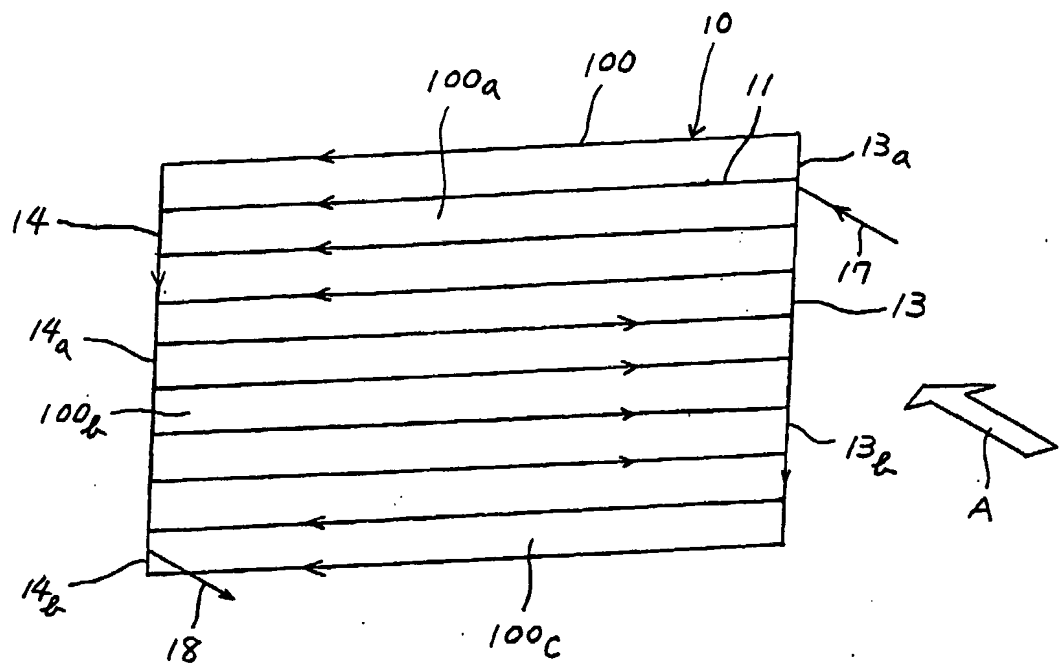
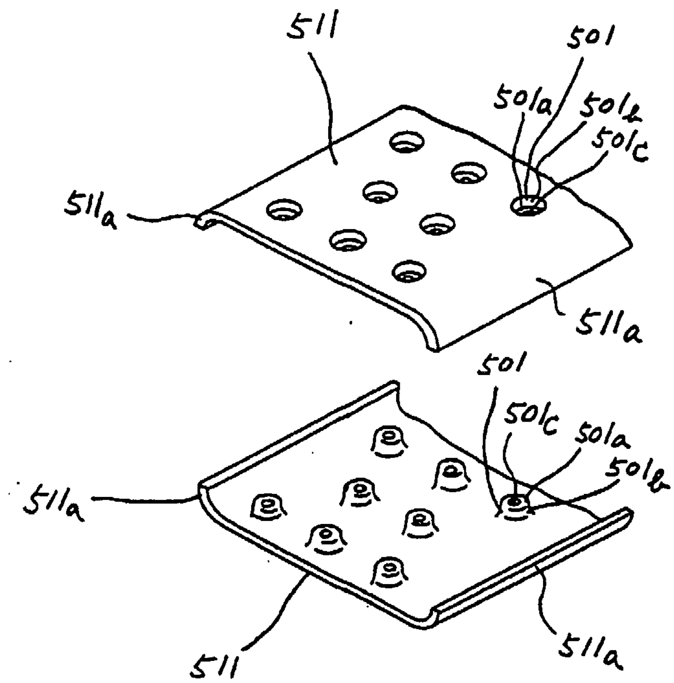


Fig. 14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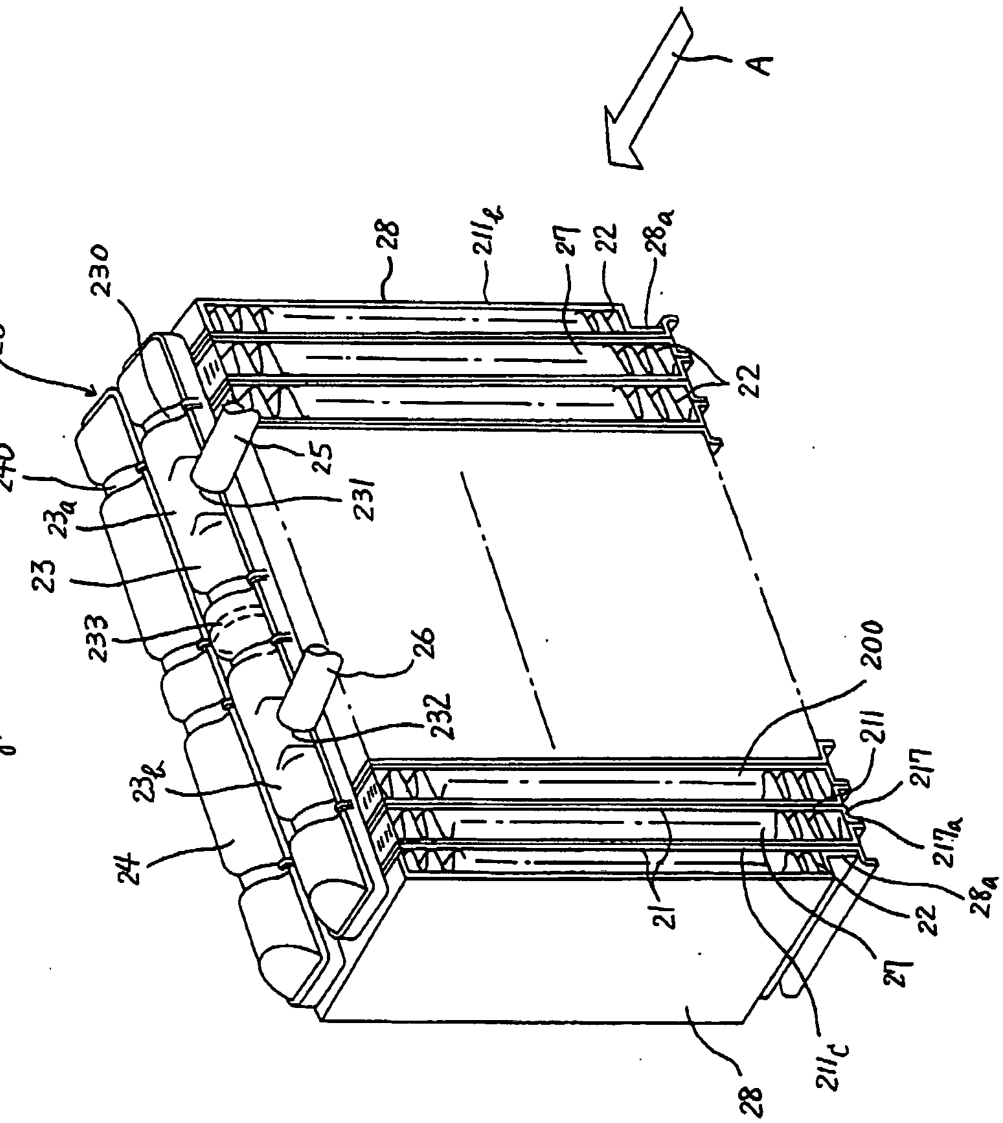
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23
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23b
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21
211c
28
211b

Fig. 15

Fig. 16

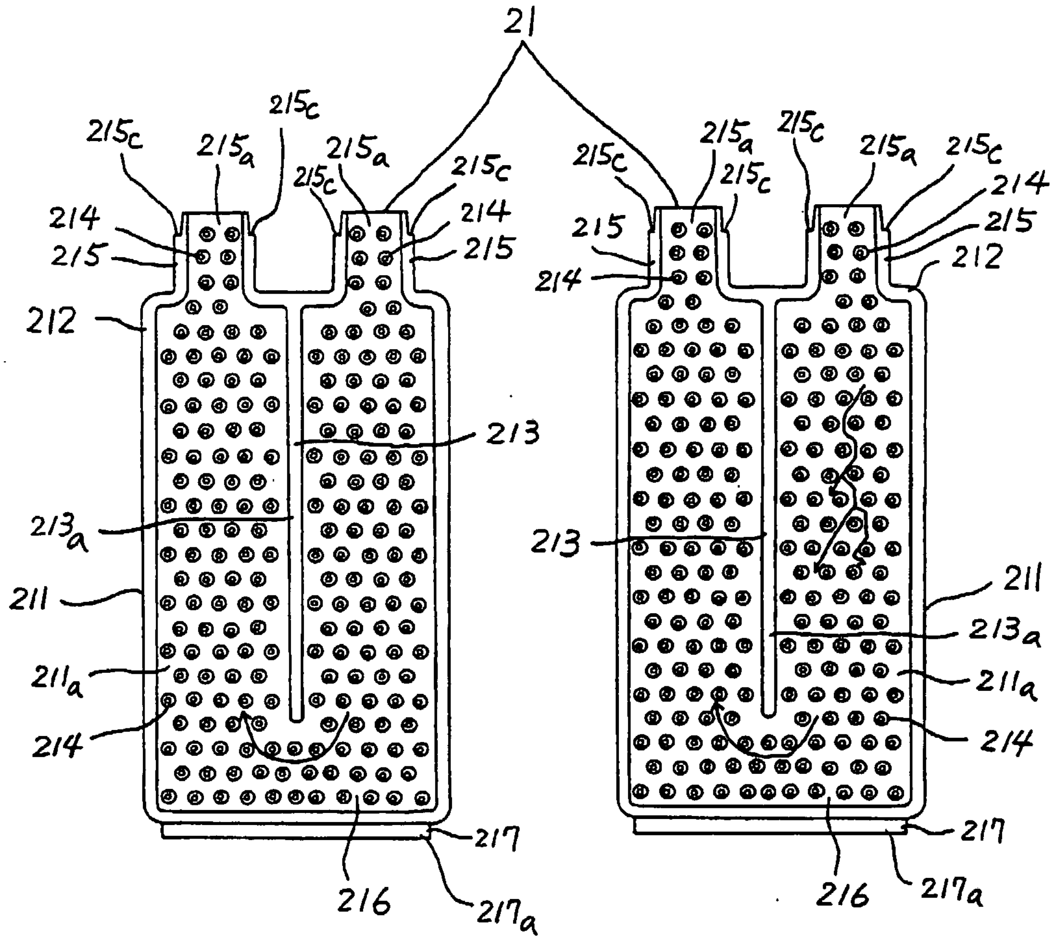
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Fig. 17

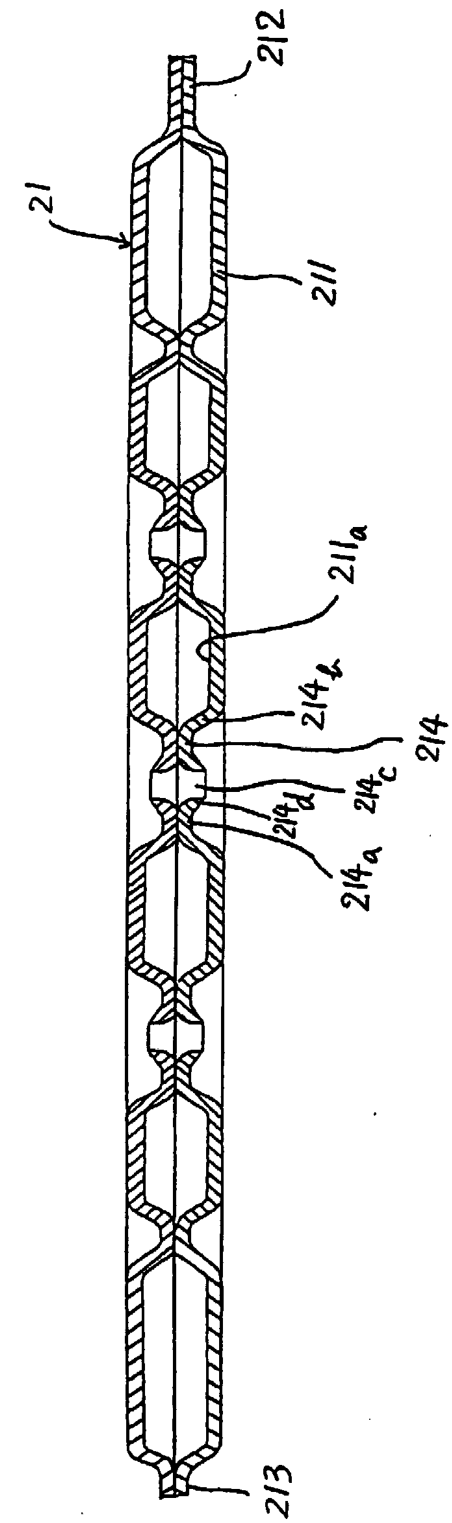
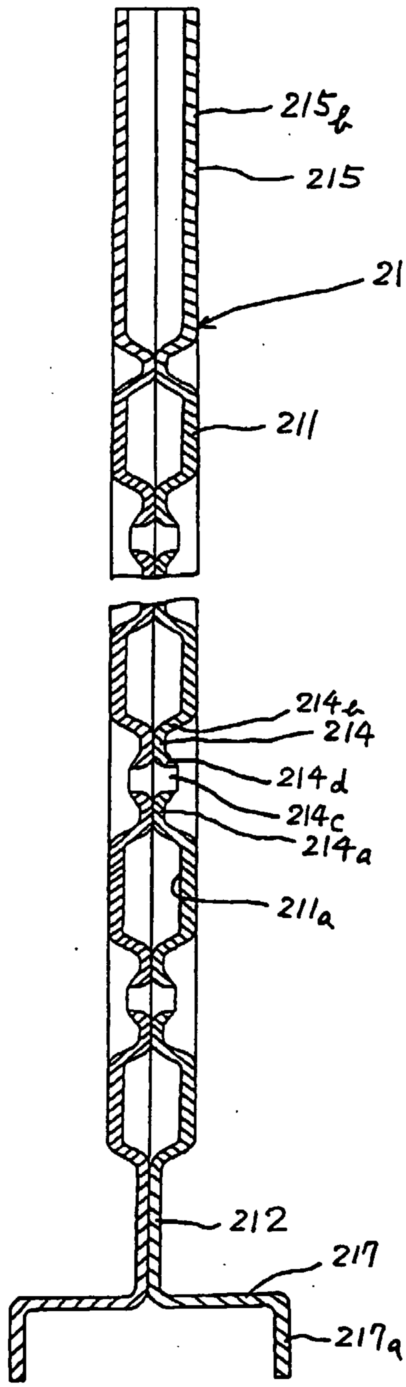


Fig. 18



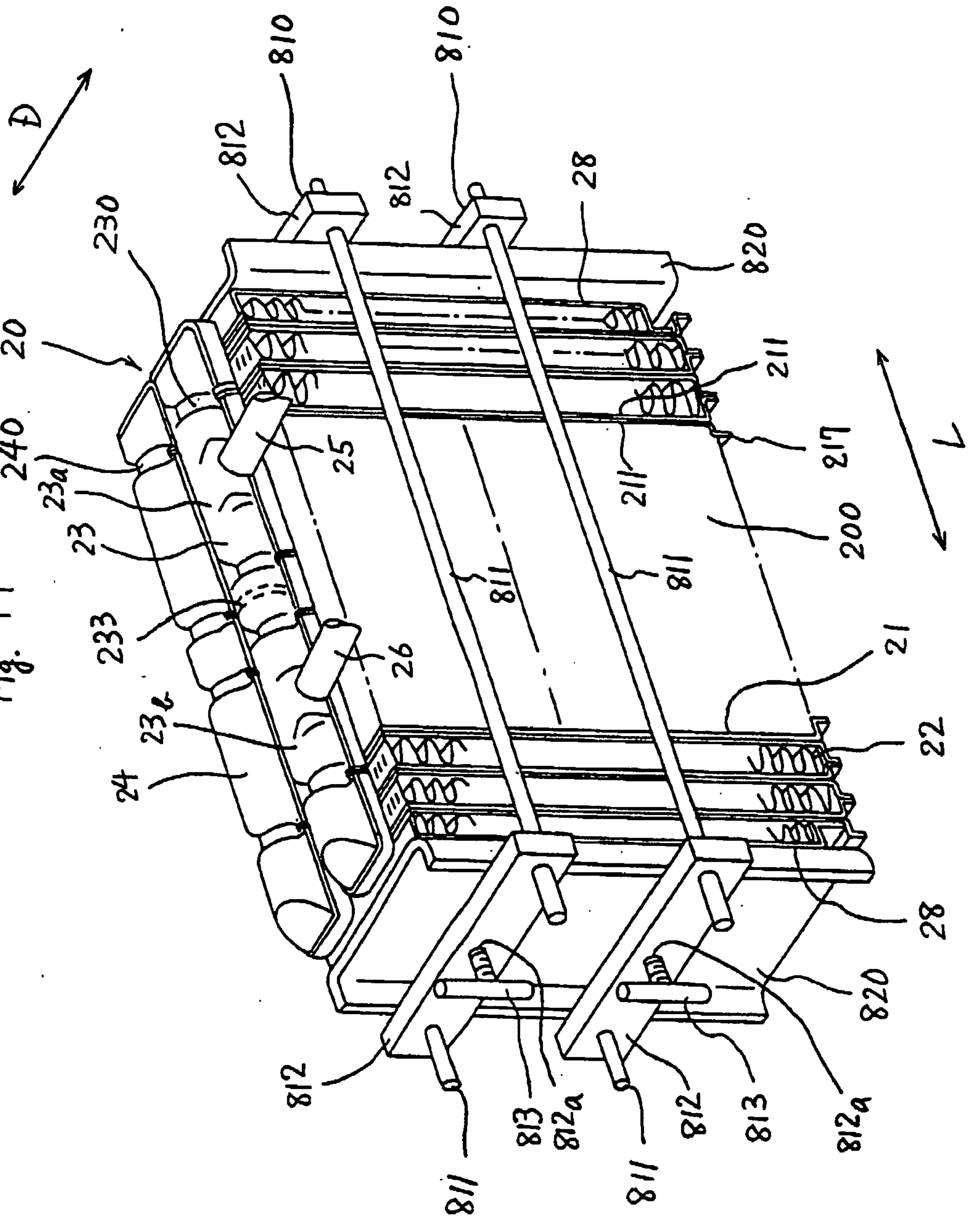

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Fig. 19

Fig. 20

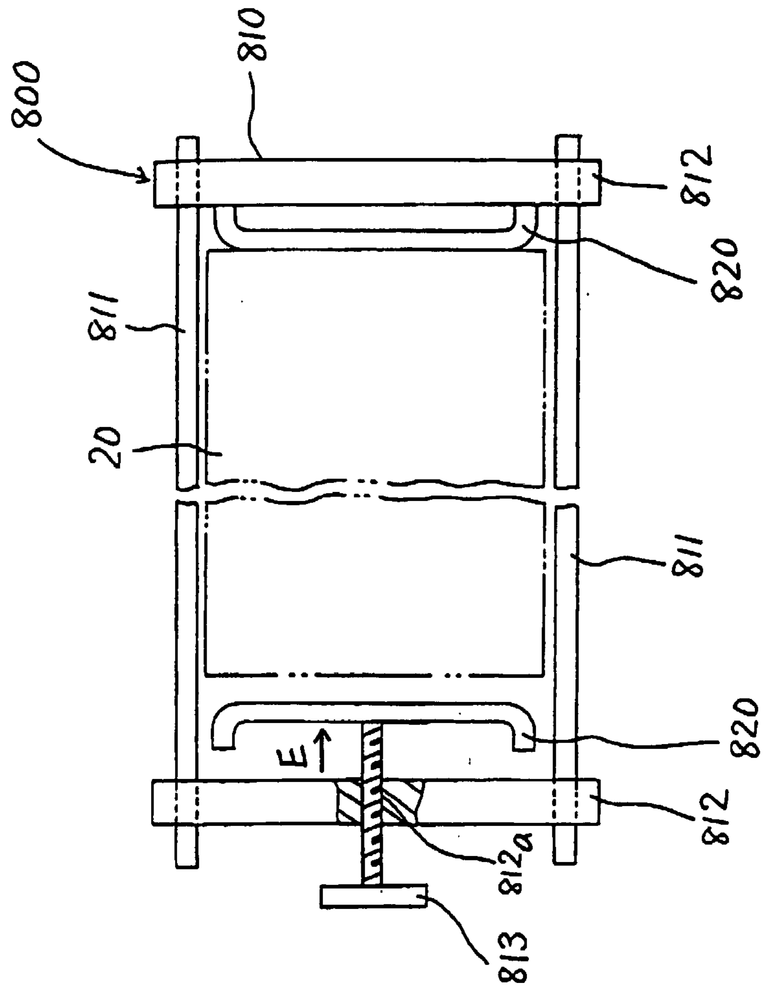


Fig. 21

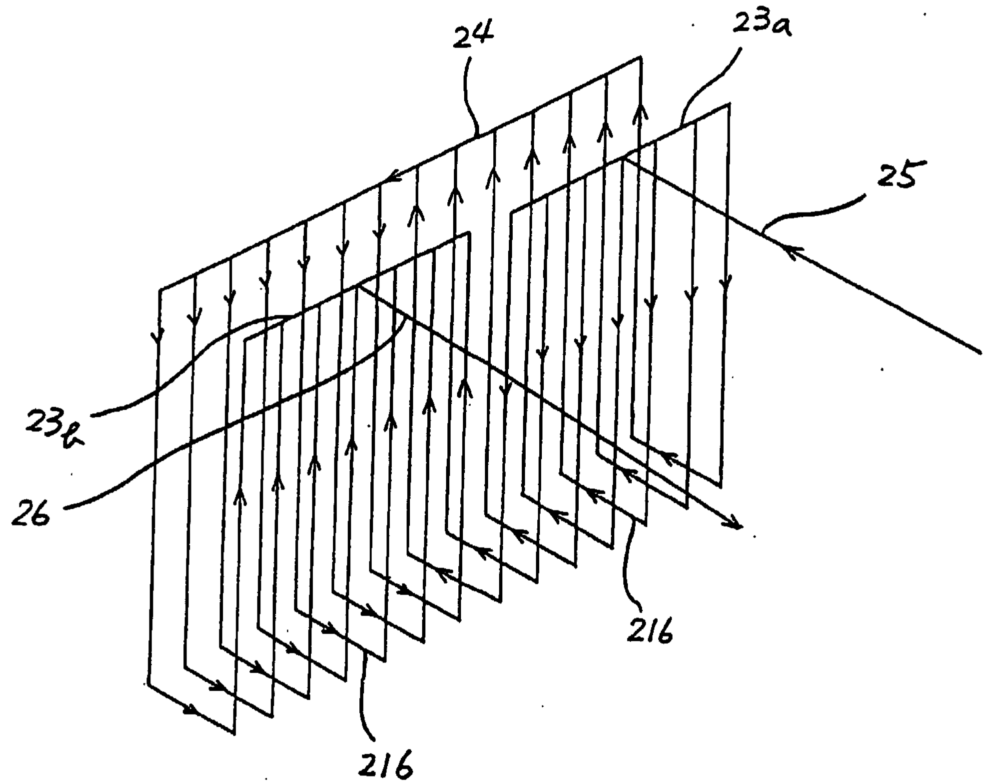


Fig. 22

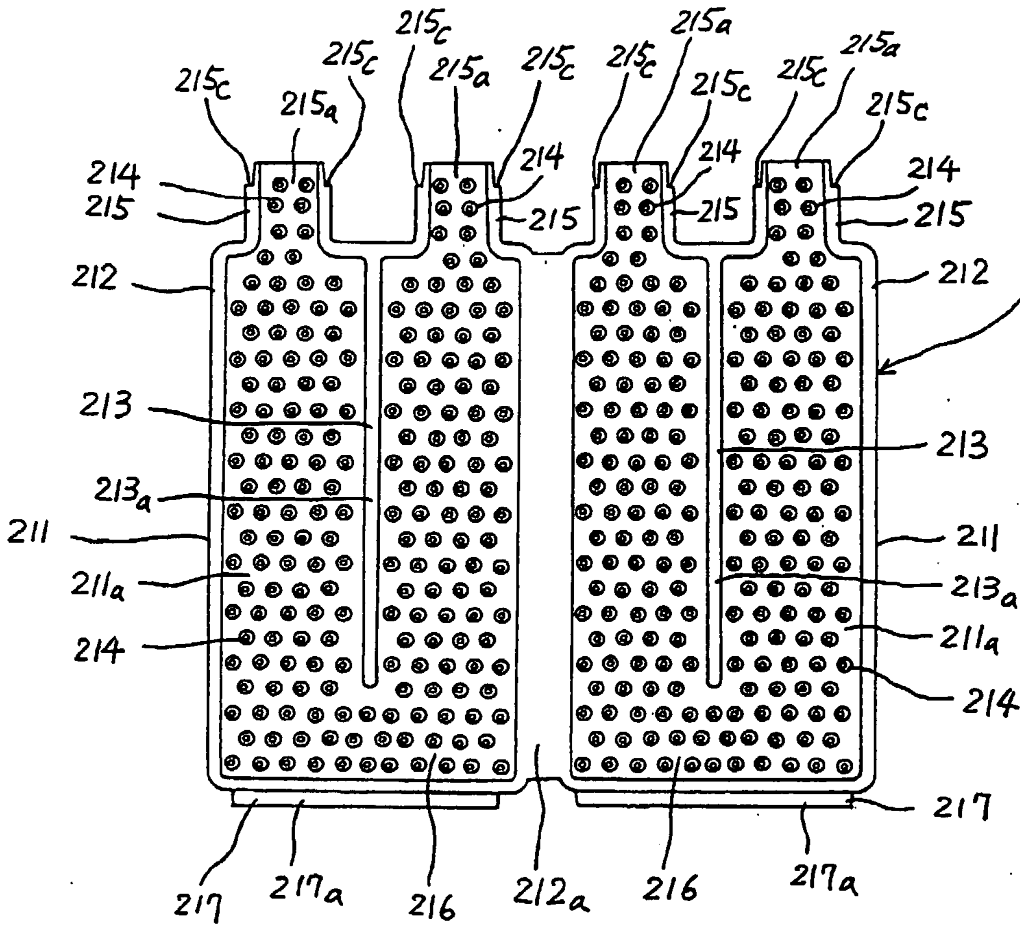
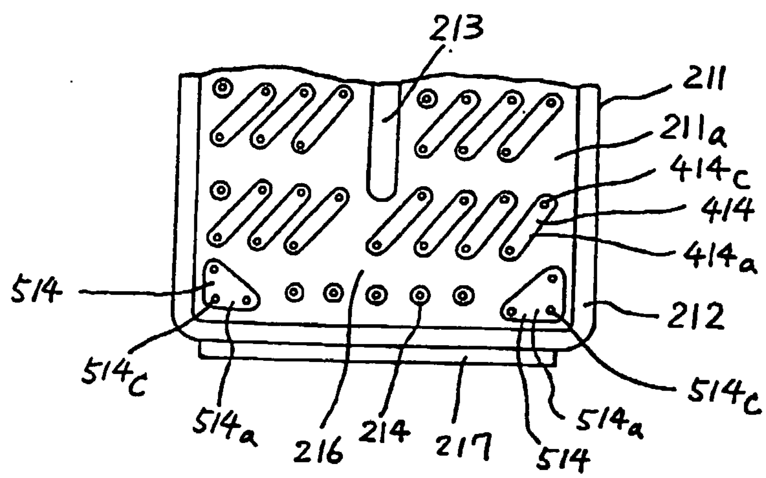


Fig. 23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212
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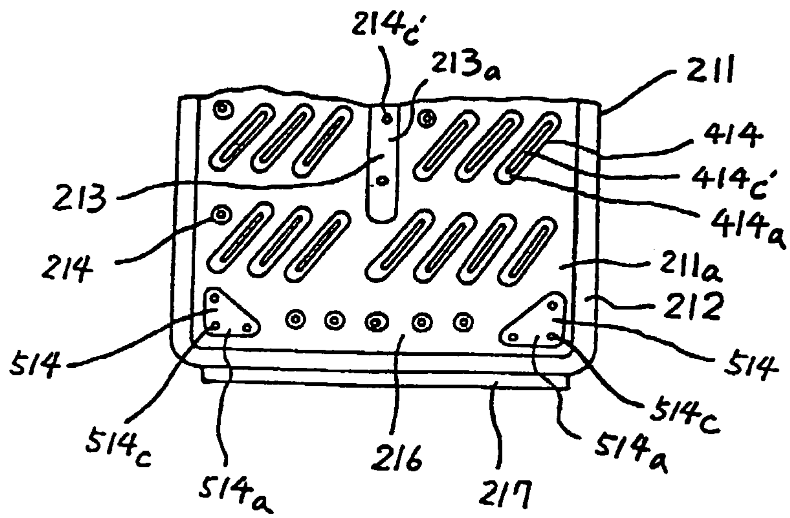
514
514c
514a

Fig. 24


214c'
213a
211
414
414c'
414a
213
214
211a
212
514
514
514c
514a
216
217
514c
514a